LALP-06-092
Summer 2006

MATERIALS RESEARCH HIGHLIGHT

The effect of shock wave profile shape on damage in copper

G.T. Gray III[1], L.B. Addessio[1], E. Cerreta[1], C.A. Yablinksy[1], D.D. Koller[2], R.S. Hixson[2], P.A. Rigg[2], J.D. Maestas[2]

An understanding of damage evolution in a metal subjected to shock loading is critical to the development of predictive models of interest to Department of Energy and Department of Defense programs. Many investigations of dynamic damage or spall have been performed using flat-top shock waves. These experiments have shown that dwell time, strain rate, and peak stress can each influence the damage evolution. Metals that are subjected to direct high-explosive-driven shock loading, however, exhibit a triangular or Taylor wave loading/unloading profile. Here the influence of shock wave profile shape on damage processes is investigated to understand the effects of peak stress and the development of tension in a specimen subjected to spallation loading.

Introduction

Dynamic tensile damage occurs when rarefaction waves within a material interact to produce tensile stresses that exceed the threshold for damage initiation[1]. If the tension is of sufficient amplitude a new interface can form, creating a "spall layer." In some cases where complete spall does not occur, significant incipient spallation damage may still exist. Plate impact experiments have been utilized in the past to probe the influence of peak stress on the damage field within shocked specimens. Evidence that a damage field or spall layer has been created is often obtained using velocity interferometer for any reflector (VISAR)[2]. In general, the free surface velocity profile obtained using VISAR shows ringing consistent with wave reflections within a layer thinner than the original sample. The experiments described here investigate flat-top, triangular, and ramp-wave damage processes in copper during spallation loading. A layered flyer plate technique is utilized to produce a triangular shock and a ramp wave for loading and unloading in the target material. A detailed description of this technique is given elsewhere[3]. Real-time VISAR measurements combined with analysis of soft recovered samples is used to examine the damage processes in copper subjected to three different loading profiles.

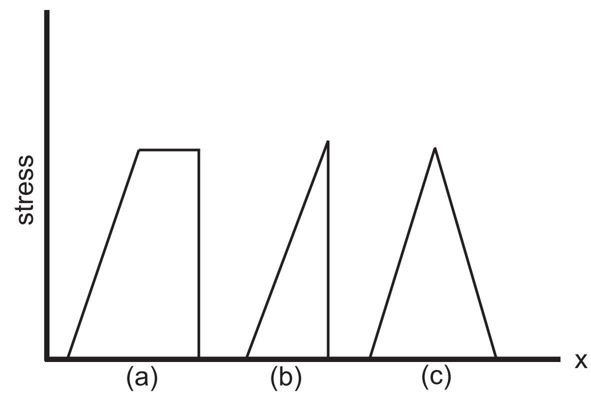

Figure 1. Schematic of (a) flat-top shock, (b) triangular shock, and (c) ramp wave.

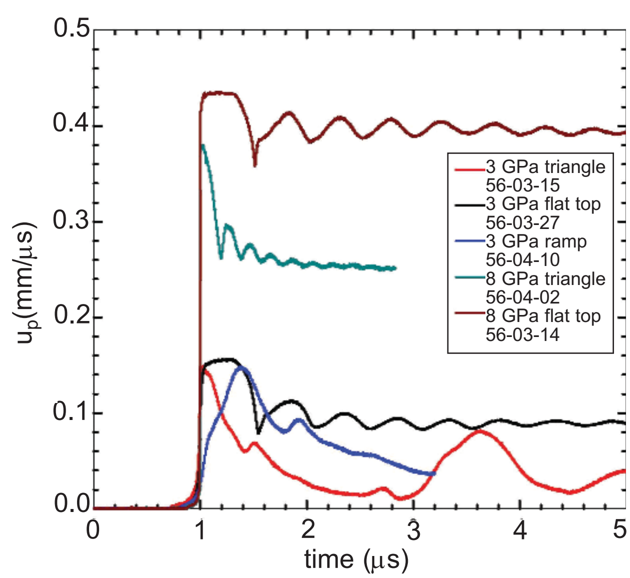

Figure 2. VISAR records for plate impact recovery experiments.

Results and discussion

Plate impact experiments were conducted using a smooth bore, 50-mm diameter gas gun. A schematic of the three distinct loading profiles is given in Figure 1. These profiles will be referred to as flat-top shock, triangular shock, and ramp-wave loading, respectively. The influence of these three different wave profiles on damage evolution was investigated at two different peak shock pressures in five flyer plate experiments. VISAR results were obtained from each specimen and are given

[1]*Structure/Property Relations, Materials Science and Technology Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
[2]*Shock and Detonation Physics, Dynamic Experimentation Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA*

G.T. Gray III received his Ph.D. in materials science and engineering from Carnegie Mellon University and is a Laboratory Fellow in the Structure/Properties Relations group of Los Alamos National Laboratory.

L.B. Addessio was a graduate research assistant in the Structure/Property Relations group and is working toward a Ph.D. in materials science and engineering at the Colorado School of Mines.

E. Cerreta, Structure/Property Relations technical staff member, received her Ph.D. in materials science and engineering from Carnegie Mellon University.

C.A. Yablinsky was a graduate research assistant in the Structure/Property Relations group and is working toward a Ph.D. in materials science and engineering at The Ohio State University.

D.D. Koller received her Ph.D. in materials science and engineering from the Colorado School of Mines and is a technical staff member in the Shock and Detonation Physics group of Los Alamos.

Laboratory Fellow R.S. Hixson received his Ph.D. in physics from Washington State University and is group leader of the Laboratory's Shock and Detonation Physics group.

P.A. Rigg received his Ph.D. in physics from Washington State University and is a technical staff member in the Shock and Detonation Physics Group of Los Alamos National Laboratory.

J.D. Maestas is a graduate research assistant in the Shock and Detonation Physics group of Los Alamos National Laboratory and is working on her bachelor's degree at the University of New Mexico.

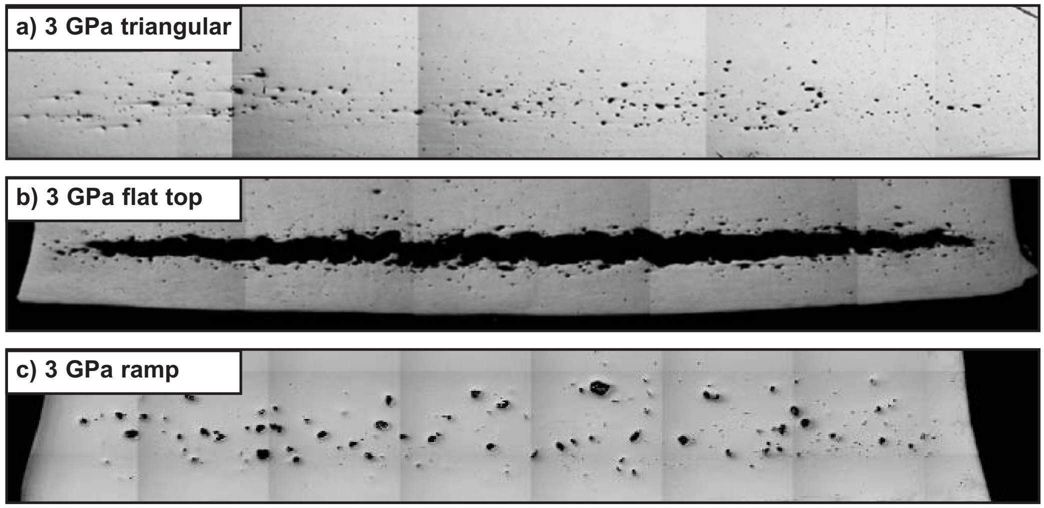

Figure 3. Composite of the optical metallography of the recovered specimens.

in Figure 2. In addition to the VISAR experiments, soft recovery experiments were conducted to allow for postmortem metallography of the specimens. These specimens were cross-sectioned parallel to the loading direction and examined optically. A composite of the optical images of the 3 GPa recovered copper specimens is shown in Figure 3.

The influence of wave profile may be observed most clearly in the 3 GPa experiments. The flat-top shock wave results in highly localized damage as observed in Figure 3b. The ringing in the 3 GPa flat-top shock VISAR data observed in Figure 2 is the result of this free surface within the specimen. In the 3 GPa triangular-wave shocked specimen, a layer of small diameter voids is observed (Figure 3a), however, the distribution of this damage indicates that the tensile stresses within the specimen during shock loading were distributed over a larger volume of material as compared to the flat-top shock loaded specimen. In Figure 2 the particle velocity for the 3 GPa triangular shock does not show the ringing observed in the flat-top shock but does indicate wave reflections that are likely due to this layer of small voids. Finally, in the ramp-wave experiments, the damage consists of a scattered field of large ductile voids as observed in Figure 3c. This indicates that the damage region was under tension for a significantly longer period of time and over a much larger volume than the triangular shock specimen. In Figure 2 the VISAR data does not suggest any indication of damage having occurred within the specimen.

Conclusions

Shock wave profile shape and peak stress are shown to influence the damage evolution within high purity copper. These experiments provide insight into the development of damage during shock loading and the relation of damage evolution to the interaction of compression and release waves within a specimen. Differences in shock-hardening effects related to shock wave profile were not determined here. Future work will focus on a systematic comparison of the dynamic work-hardening processes operative during shock and ramp loading of copper.

References

[1]T. Antoun, L. Seaman, D. Curran, G. Kanel, S. Razorenov, A. Utkin, *Spall Fracture* (Springer, New York, 2002), p. 26.
[2] L. M. Barker, R. E. Hollenbach, *J. Appl. Phys.* **43**, 4669 (1972).
[3] D. D. Koller, R. S. Hixson, G. T. Gray, P. A. Rigg, L. B. Addessio, E. K. Cerreta, J. D. Maestas, C. A. Yablinsky, *J. Appl. Phys.* **98**, 1035181 (2005).